Dynamics of Suspended Sediments in an Optically Deep Coastal Region

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LONG-TERM GOALS

The long-term goals associated with this project are to understand the suspension, transport, and deposition of fine sediments and their effect on optics in coastal regions.

OBJECTIVES

The specific objectives of this project are (1) to obtain direct oceanic measurements of the upward flux of fine sediments due to turbulence and the corresponding downward flux due to gravitational settling; (2) to test observationally the nearly universal assumption that fine sediments are transported vertically by turbulence in the same manner as heat (i.e., that turbulent Schmidt and Prandtl numbers are equal); and (3) to quantify observationally the relationship between the upward flux of fine sediments from the seafloor and the bottom stresses produced by waves and currents.

APPROACH

The approach requires measurements obtained by a near-bottom array of acoustic Doppler velocimeters (ADVs) (e.g., Voulgaris and Trowbridge, 1998), manufactured by Sontek, Inc., and a nearby array of Laser In-Situ Sizing and Transmissometry (LISST) sensors (Agrawal and Pottsmith, 2000), manufactured by Sequoia Scientific, Inc. ADVs measure the three-dimensional velocity vector and the acoustical backscatter intensity in a sample volume with a scale of 1 cm. LISSTs measure particle size distribution, and a modified LISST with settling tube (LISST-ST) measures settling velocity as a function of particle size. ADV measurements permit calculation of ensemble-averaged (in this case, hour-averaged) acoustical intensity, denoted $<I>$, and covariance of vertical velocity and acoustical intensity, denoted $<I'w'>$. The idea is that LISST and LISST-ST measurements of particle size distribution and density will determine proper interpretation of the acoustical measurements, permitting meaningful computation of the upward flux of sediment due to turbulence, $\Sigma<c'_n w'>$, as well as the downward flux due to settling, $\Sigma w_{sn}<c_n>$. Here c_n is sediment concentration in the *nth* size class, w_{sn} is the corresponding settling velocity, primes denote turublent fluctuations, brackets denote hour averages, and summation is over all size classes. Measurements of $\Sigma<c'_n w'>$ and $\Sigma w_{sn}<c_n>$ will permit evaluation of the hypothesis that turbulent Schmidt and Prandtl numbers are equal and quantification of the relationship between bottom stress and sediment flux from the seafloor.

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **Dynamics of Suspended Sediments in an Optically Deep Coastal Region**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,,Woods Hole,,MA,02543**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT **The long-term goals associated with this project are to understand the suspension, transport, and deposition of fine sediments and their effect on optics in coastal regions.**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

WORK COMPLETED

This project is a collaborative effort with Y. C. Agrawal, of Sequoia Scientific, Inc., who is funded under a separate grant. The primary focus of the collaboration is participation in the 2000 and 2001 Hyperspectral Coupled Ocean Dynamics Experiments (HYCODE) at Rutgers University's LEO-15 site off New Jersey.

During the 2000 experiment, Trowbridge designed and supervised fabrication and deployment of a bottom tripod supporting ADVs at 0.7 and 3.5 m above bottom, fast-response thermistors near the ADV sample volumes, and a temperature-conductivity sensor at 4.5 m above bottom. Agrawal designed and supervised fabrication and deployment of a bottom tripod supporting a LISST at 2.0 m above bottom, a LISST-ST at 1.0 m above bottom, and a Miniature Scattering and Transmissometry (MSCAT) sensor at 0.2 m above bottom. Deployment of both tripods occurred during July near the main node at LEO-15, at a position where the mean depth is 16 m and the sand bottom is flat except for wave-formed ripples. Recovery occurred in September.

During the 2001 experiment, Trowbridge and Agrawal redeployed the two tripods at LEO-15. Trowbridge added a dop-beam, which measures vertical velocity and echo intensity at high frequency (375 Hz) and high resolution (0.012 m) along a vertical path with a range of 1.5 m. The dop-beam measurements will provide far more information about vertical flux of suspended sediments than will the ADVs.

Work to date also includes analysis of near-bottom ADV and LISST measurements obtained during the ONR-funded Coastal Mixing and Optics (CMO) experiment, which occurred during 1996-97 in the "mud patch" on the New England shelf, at a water depth of 70 m. As part of CMO, A. J. Williams, of the Woods Hole Oceanographic Institution, deployed a bottom tripod with an array of three ADVs, all at a height of 0.4 m above bottom, and Y. C. Agrawal deployed a nearby tripod with a LISST. The CMO measurements are useful for preliminary work on interpretation of combined ADV and LISST measurements, but are insufficient to address the above objectives, because LISST and ADV measurements were obtained at only one height and settling velocity was not measured.

RESULTS

Agrawal's results to date are summarized in a separate report. Trowbridge's results to date are based on analysis of ADV and LISST measurements obtained during CMO, and also on analysis of ADV and dop-beam measurements obtained during the 2000 and 2001 HYCODE experiment at LEO-15.

Analysis of ADV measurements during HYCODE 2000 indicates that a differencing operation (Trowbridge, 1998), performed on records obtained from the three spatially separated ADVs, removes wave contamination from estimation of the turbulence covariance $<I'w'>$. ADV-derived records of $w_s <I>$ and $<I'w'>$ are well correlated and consistent in magnitude (Figure 1), if one assumes a fixed settling velocity of $w_s = 5 \ x \ 10^{-4}$ m/s, which is a reasonable estimate for the HYCODE region (Agrawal and Pottsmith, 2000; Hill et al., 2001). Agreement between $w_s <I>$ and $<I'w'>$ is consistent with a balance between $\Sigma w_{sn} <c_n>$ and $\Sigma <c'_n w'>$, and indicates that, with proper interpretation based on LISST measurements, ADV measurements can be used to determine the vertical sediment flux due to turbulence.
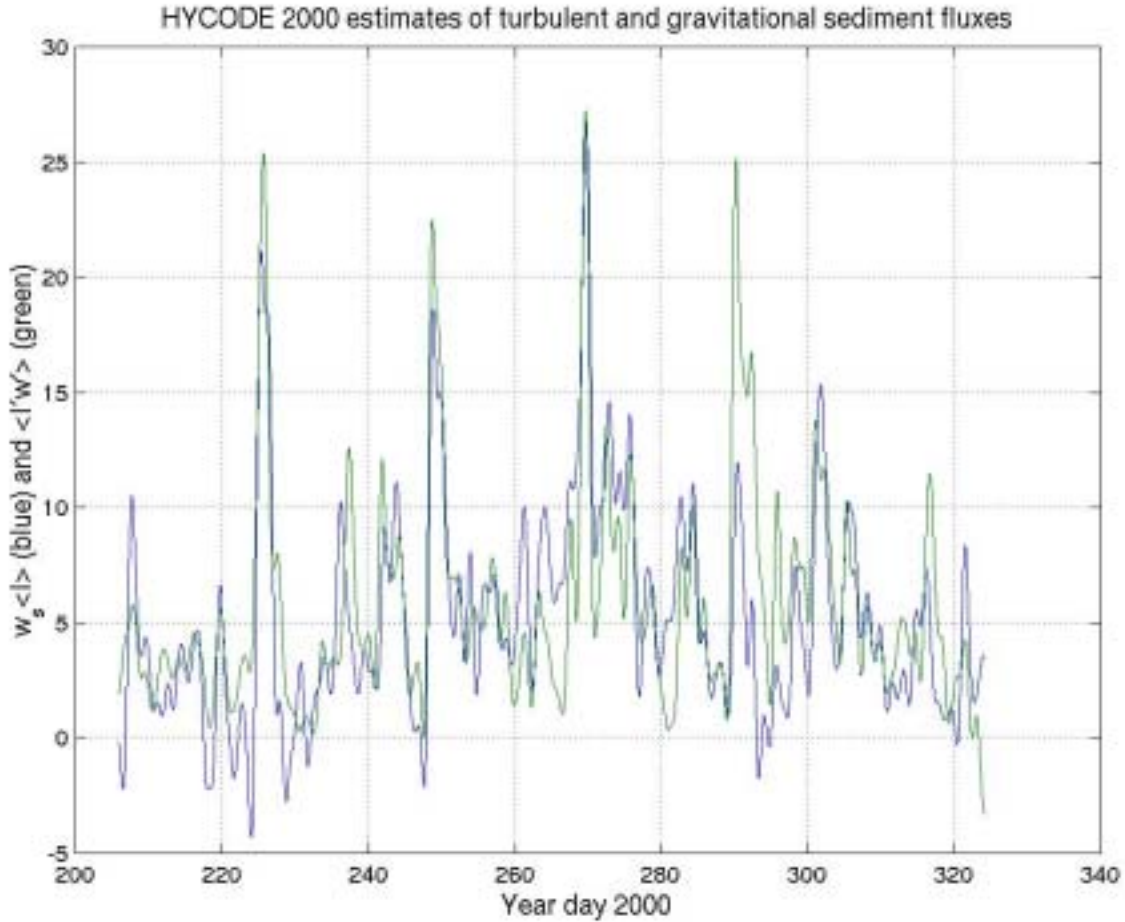
Figure 1: Estimates of vertical fluxes of sediment due to settling and turbulence during CMO. These estimates were obtained from ADV records of intensity I and vertical velocity w < I > and < I'w' > by using a fixed gain and offset to convert intensity I to concentration, and assuming a fixed settling velocity of $w_s = 5 \times 10^{-4}$ m/s. The good agreement between estimates of settling and turbulent fluxes suggests that, with proper interpretation based on LISST data, ADV measurements will provide meaningful estimates of turbulent sediment flux.

Preliminary analysis of the dop-beam measurements obtained during the 2001 HYCODE experiment have produced cospectra of vertical velocity and acoustic backscatter intensity (Figure 2), which indicate a vertical flux of suspended sediment at the expected scales. This result indicates that the dop-beam measurements will produced meaningful estimates of the vertical flux of suspended sediment.
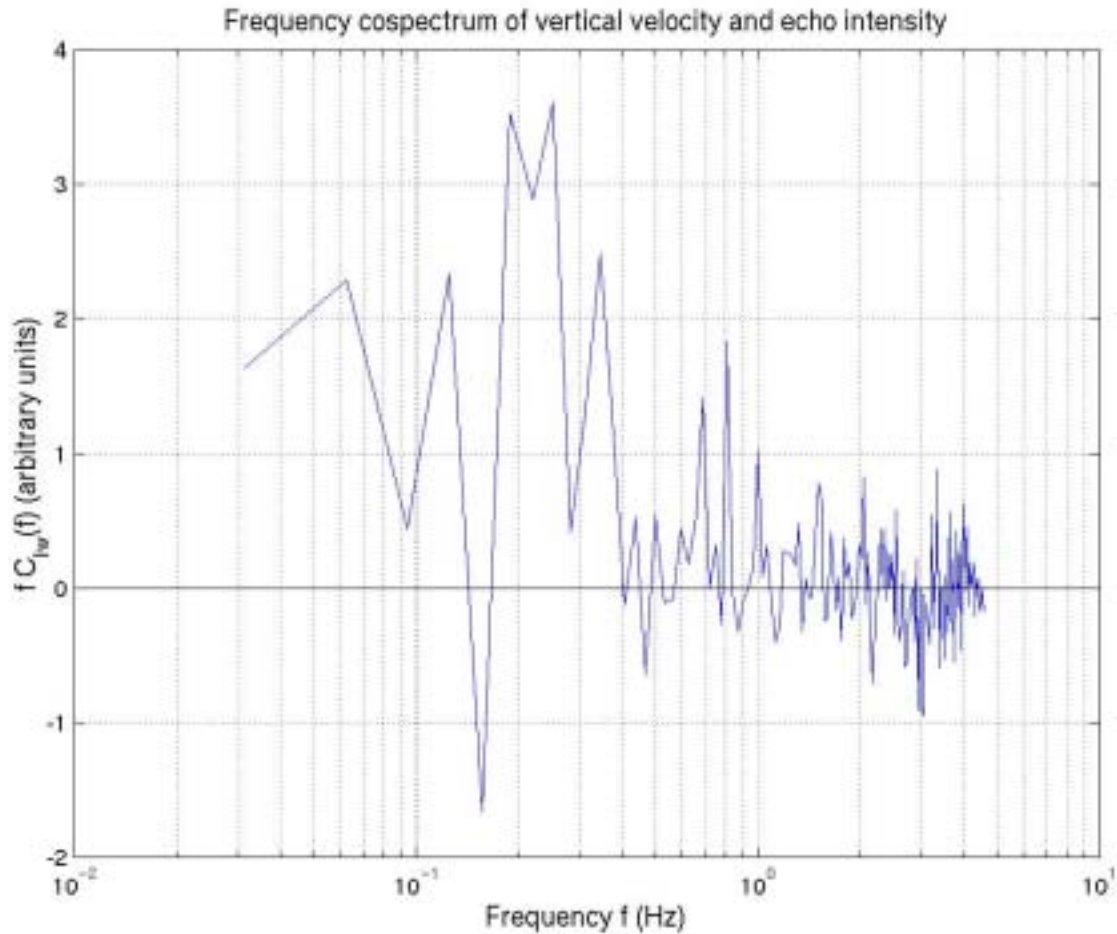
Figure 2: Results of 2001 HYCODE experiment at LEO-15: a sample cospectrum of vertical velocity and acoustic backscatter intensity, which is proportional to the vertical flux of suspended sediment. This result indicates that the dop-beam measurements can produce quantitative estimates of the turbulent flux of suspended sediment.

IMPACT/APPLICATIONS

If successful, this study will produce the first direct measurements of sediment flux from the seafloor. This quantification of the bottom boundary condition for fine suspended sediment will dramatically improve numerical simulations of sediment concentrations in coastal regions, both in the case of HYCODE and in more general applications.

RELATED PROJECTS

Trowbridge's and Agrawal's participation in the ONR Coastal Mixing and Optics program have provided techniques and measurements required for execution and testing of the analyses carried out during this study.

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